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The attached documents are exact copies of the European patent application described on the following page, as originally filed.

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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

00204797.5

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

I.L.C. HATTEN-HECKMAN

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Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

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MRI apparatus

The invention relates to a magnetic resonance imaging apparatus (MRI apparatus) comprising a gradient coil assembly for generating gradient magnetic fields in an imaging volume, wherein the gradient coil assembly comprises at least three gradient coils for generating three different gradient magnetic fields.

Such a MRI apparatus is known in general and is widely used. In such an apparatus it is necessary to superimpose strong, rapidly changing gradient magnetic fields on a very homogeneous static magnetic field. These gradient magnetic fields spatially define the imaging volume, and are produced by coils carrying precisely controlled current pulses. Because of the so-called skin effect, the currents do not always flow along the intended paths in an x-, y- or z-gradient coil during or immediately after activation. Moreover, during or immediately after activation eddy currents could be induced in the other coils, in an RF screen or other parts of the apparatus. Such effects cause time-dependent fields which cause the delay of the field to be a function of the position in space. This results in an integral field error with time at its dimension which can be written as a series of Legendre coefficients, each having one or more time constants. Consequently, artifacts may occur in certain sequences used by the MRI apparatus.

A known solution consists in the use of Litze wires. The manufacturing process with Litze wire is expensive. The placement of the Litze wire is not very precise, resulting in an unpredictable eddy current behaviour in the magnet, which results in image quality problems. Another known solution consists in the use of narrow conductors. This is more expensive than wide conductors. It also means more dissipation and requires higher voltages.

An arrangement to minimize eddy currents in MR images is known from US 5,555,251. In this arrangement gradient coils are positioned in the face of a pole piece, and thin disc shaped or ring shaped ferromagnetic parts laminated of layer cut favourably from transformer sheet material are attached to the face of the pole piece. To reduce eddy

currents in these layers, narrow, radially oriented slots are cut in these layers before lamination. These layers are placed in-between the pole piece of the magnet and the gradient coil. Thus only eddy currents in these parts outside the gradient coil are reduced.

It is therefore an object of the invention to provide means for compensating self induced eddy currents in the gradient coil assembly of an MRI apparatus as mentioned above.

This object is achieved by an MRI apparatus according to claim 1 wherein a conductive element is provided in close proximity to at least one of the gradient coils for compensating self induced eddy currents in the gradient coil assembly. The invention is based on the general idea to introduce pieces of a conductive material into the MRI apparatus so that the undesirable high-order behaviour can be suppressed and the character of the short term self-eddy field becomes similar to that of the gradient coils. It has been recognized that self induced eddy currents can best be compensated by locating the conductive element in close proximity to the gradient coil the self induced eddy current of which shall be compensated. In general, only one or several certain gradient coils or all gradient coils can be provided with a conductive element which can be identical or adapted to the respective gradient coil.

Preferred embodiments of the invention can be found in the dependent claims.

In preferred embodiments of the invention the conductive element is provided inside the at least one gradient coil or between an inner gradient coil element and an outer gradient coil element of the at least one gradient coil. The location of the conductive element may be a fixed part of the gradient coil and hence do not concern apparatus specific adjustment. The conductive element may also be provided in a different location within the apparatus. For example it may be integrated with the RF shield. The slitting of the RF shield can be adapted thereto, meaning that it is not designed for minimum short-term eddy currents, but for the appropriate short-term eddy currents.

Further, in another aspect of the invention the conductive element comprises an active or passive coil loop which can be short-circuited in itself or which can be connected

to a separate loop amplifier. In both aspects the dimensions, shape and position of a short-circuited loop determine what field profile is corrected. The wire thickness determines the time constant when a short-circuited loop is used. Small current loops of this kind in principle induce only a time delay. Sometimes, however, acceleration is desirable. Positive currents can also be realized in the loop near the imaging region by connecting such a loop to a loop in the outer region. As a rule, the above short- term behaviour is determined to a high degree by the design of the conductive element.

In another embodiment of the invention the loop is driven by a signal taken from the at least one gradient coil using a transformer. Such a transformer could be made with parts of the gradient coil, e. g. by putting a pickup-loop at the end of the gradient coil or at the outer side.

In another preferred embodiment of the invention the conductive element comprises a conductive pad, in particular a conductive foil or a conductive plate. Such a conductive foil can be a copper foil glued to the inner side of the gradient coil. Varying the dimension and/or slitting can restrict its effect to mainly one specific field shape and mainly one specific coil. Variation of the thickness influences the time constant and hence the special time delay. It is also possible to provide for small metal plates, e. g. having a diameter of about 30 cm. Such conductive elements can be used for the x-, for the y- as well as for the z-gradient coil in general. The conductive pads or plates do not compensate as good as coils, i. e. they do not have exactly the right field profile and have interactions with other coils that are switched, but this might be sufficient for many cases. The conductive pads or plates solution is cheaper and easier to manufacture.

The invention will now be explained in more detail with reference to the appended drawings, in which

Fig. 1 shows the general layout of a gradient coil assembly in a MRI apparatus,

Fig. 2 shows the principle of the invention, by way of a first embodiment,

Fig. 3 shows the form of the gradient current used in the embodiment of Fig. 2,

Fig. 4 shows a second embodiment of the invention,

Fig. 5 shows a third embodiment of the invention,

Fig. 6 shows a fourth embodiment of the invention,

Fig. 7 shows a correction loop for an x-gradient coil according to the invention,

Figs. 8A, 8B show the form of an inner and an outer gradient coil element of an x-gradient coil,

Fig. 9 shows a cross section of a z-gradient coil,

Fig. 10 shows a cross section of a correction coil for a z-gradient coil according to the invention and

Fig. 11 shows a cross section of another embodiment of a correction coil for a z-gradient coil.

Figure 1 shows the general layout of a MRI apparatus 1 comprising a gradient coil assembly. The MRI apparatus comprises a static field magnetic coil 2, x-gradient coils 3, y-gradient coils 4 and z-gradient coils 5. Each of these gradient coils 3, 4, 5 comprises a pair of coil elements to generate strong, rapidly changing gradient magnetic fields spatially defining the imaging volume. Each coil set is connected to an independently controlled power supply. In addition to producing gradients oriented along x, y or z axis, by powering the gradient coils in combination, it is possible to generate magnetic field gradients in any orientation. The gradients generated by these coils should be linear over the imaging volume, and should be stable for the duration of the applied gradient. However, eddy currents are generated by the changing gradients in conducting parts like the metal shields of the magnets. The eddy currents in turn are producing unwanted gradient field at the place of interest,

which causes problems, like artifacts in images. Also in the gradient coils themselves eddy currents are self induced causing such artifacts.

The principle of the invention is shown in Figure 2. This shows a possible arrangement of a conductive element 52 in the form of a loop around the z-axis and located at the inner side of the z-gradient coil 51. The z-coil 51 of this arrangement comprises a three turns and the correction coil 52 comprises one turn, symmetrically arranged with respect to the z-axis and placed around the imaging volume. Both coils could for example be made from a wire having a thickness of 1 mm. The correction coil 52 could also be a foil glued to the inner side of the gradient coil support.

The correction coil 52 should be driven by a current as shown in Figure 3. Therein it can be easily recognized that the current I is time dependent. I′ represents the time derivate of that current I, multiplied by some time constant.

Figure 4 shows schematically the arrangement of a conductive element 71 for compensation of eddy currents with respect to a gradient coil 6. The gradient coil 6 is connected to an amplifier 8 for driving the gradient coil. The conductive element is formed as a conductive closed loop which is located in close proximity to the gradient coil 6.

Another embodiment of the invention is shown in Figure 5 which shows another correction coil 72 having its own amplifier 9 for driving the correction coil 72.

Another embodiment of a correction coil 73 is shown in Figure 6. Therein the correction coil 73 is driven by a transformer 10 located in the cable between the amplifier 8 and the gradient coil 6. Such a transformer 10 could also be made with parts of the gradient coil 6, e. g. by putting a pickup-loop at the end of the gradient coil 6 or at the outer side thereof.

A possible layout of a correction coil is shown in Figure 7. Therein the layout of a correction coil 32 located at the inner side of the x-gradient coil 31 along the z-axis is shown. The correction coil 32 can either be a closed loop, or it can be actively driven, either via a dedicated amplifier or e. g. inductively from the x-gradient coil 31 itself via a transformer as shown in Figure 6.

The layout of an inner gradient coil element 53 and an outer gradient coil element 54 of a x-gradient coil is shown in Figures 8A, 8B. Between the inner and the outer gradient coil elements 53, 54 a conductive element can be located according to the invention.

Further embodiments of correction coils according to the invention are shown in Figures 9 to 11.

Figure 9 shows an example of a z-gradient coil in cross section. The rectangles are cross sections of the conductors and only one quadrant of the plane is shown since the rest is symmetric.

Figure 10 shows an example of a correction coil, also in cross section. This coil makes a C30-type field (in Legendre series). The lines represent a collection of thin wires.

Figure 11 shows another example of a correction coil, this time generating a C10+C30-type field. This could also be a wide copper foil or a slitted copper foil, i.e. slitted along the circumference. In that case it looks like a set of short-circuited loops again.

The correction coils have thin wires since the currents are low. The short lines shown in Figures 9 to 11 mean a series of wires next to each other.

Figure 12 shows the same inner x-coil 53 as figure 8A, but now with a conductive pad 55. This could for instance be a foil that extends over 120 degrees and has a certain width and thickness. The angle, width and z-position determine the field profile. The width and thickness determine the timeconstant.

Figure 13 is identical to figure 12, but now with a slit 56. This is to prevent or reduce eddy current from the other coils (y and z). This now looks quite a lot like a close-circuited loop.

It should be remarked that the embodiments described above are merely examples to which the scope is not limited. The invention can be implemented in many different other embodiments which are not shown herein, such as different types of gradient

coils for cylindrical magnet (oval coils, conical coils, asymmetrical coils), gradient coils for 'open' magnets, insert gradient coils, etc. The invention refers to the general idea of using conductive elements which are provided in close proximity of a gradient coil for compensating self induced eddy currents in the gradient coil assembly. Each gradient coil can have its own conductive element which can be adapted to the gradient coil in order to suppress high-order behaviour of the gradient coil and to achieve that conductive elements are provided in the gradient coil assembly such that undesirable high-order behaviour of the gradient coils is suppressed and that the character of the short term self-eddy field becomes similar to that of the gradient coils.

CLAIMS:

1. Magnetic resonance imaging apparatus (1) comprising a gradient coil assembly (3, 4, 5) for generating gradient magnetic fields in an imaging volume, wherein the gradient coil assembly (3, 4, 5) comprises at least three gradient coils (3, 4, 5) for generating three different gradient magnetic fields,
characterized in that a conductive element (71, 72, 73) is provided in close proximity to at least one of the gradient coils (3, 4, 5) for compensating self induced eddy currents in the gradient coil assembly (3, 4, 5).

2. Apparatus according to claim 1,
characterized in that the conductive element (71, 72, 73) is provided at the inside the at least one gradient coil (3, 4, 5).

3. Apparatus according to claim 1,
characterized in that the conductive element (71, 72, 73) is provided between an inner gradient coil element and an outer gradient coil element of the at least one gradient coil (3, 4, 5).

4. Apparatus according to claim 1,
characterized in that the conductive element (71, 72, 73) comprises an active or passive coil loop.

5. Apparatus according to claim 4,
characterized in that the loop is short-circuited in itself.

6. Apparatus according to claim 4,
characterized in that the loop is connected to a separate loop amplifier.

7. Apparatus according to claim 4,

characterized in that the loop is driven by a signal taken from the at least one gradient coil (3, 4, 5) using a transformer or a pickup-loop.

8. Apparatus according to claim 1,
characterized in that the conductive element (71, 72, 73) comprises a conductive pad, in particular a conductive foil or a conductive plate.

9. Apparatus according to claim 8,
characterized in that the conductive pad is slit.

10. Apparatus according to claim 1,
characterized in that conductive elements (71, 72, 73) are provided in the gradient coil assembly (3, 4, 5) such that mainly undesirable high-order behaviour of the gradient coils (3, 4, 5) is suppressed and that the character of the short term self-eddy field becomes similar to that of the gradient coils (3, 4, 5).

18.12.2000

ABSTRACT:

The invention relates to a magnetic resonance imaging (MRI) apparatus (1) comprising a gradient coil assembly (3, 4, 5) for generating gradient magnetic fields in an imaging volume, wherein the gradient coil assembly (3, 4, 5) comprises at least three gradient coils (6) for generating three different gradient magnetic fields. In order to receive self induced eddy currents in the gradient coils it is proposed according to the invention that a conductive element (71, 72, 73) is provided in close proximity to at least one of the gradient coils (6) for compensating self induced eddy currents in the gradient coil asssembly (3, 4, 5). It is thus achieved that undesirable high-order behaviour of the gradient coils is suppressed and that conductive elements (71, 72, 73) are provided in the gradient coil assembly (3, 4, 5) such that undesirable high-order behaviour of the gradient coils (3, 4, 5) is suppressed and that the character of the short term self-eddy field becomes similar to that of the gradient coils (3, 4, 5).

Fig. 4

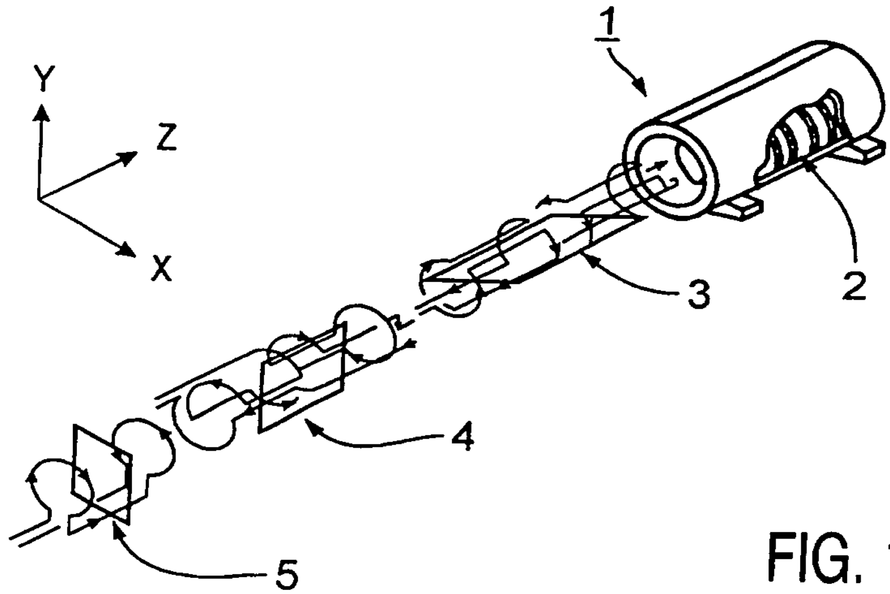


FIG. 1

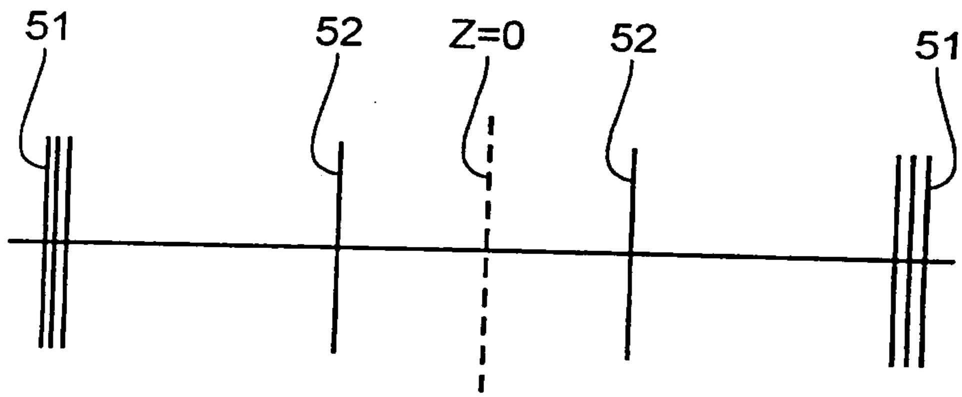


FIG. 2

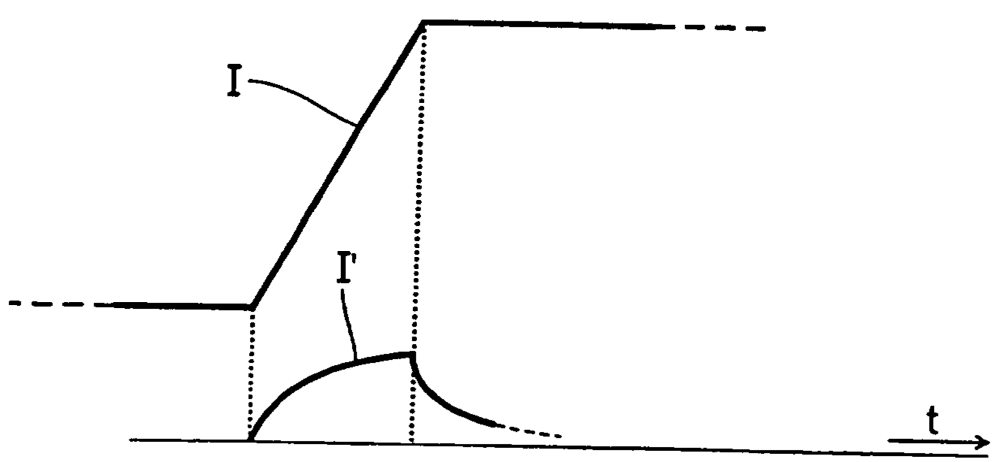


FIG. 3

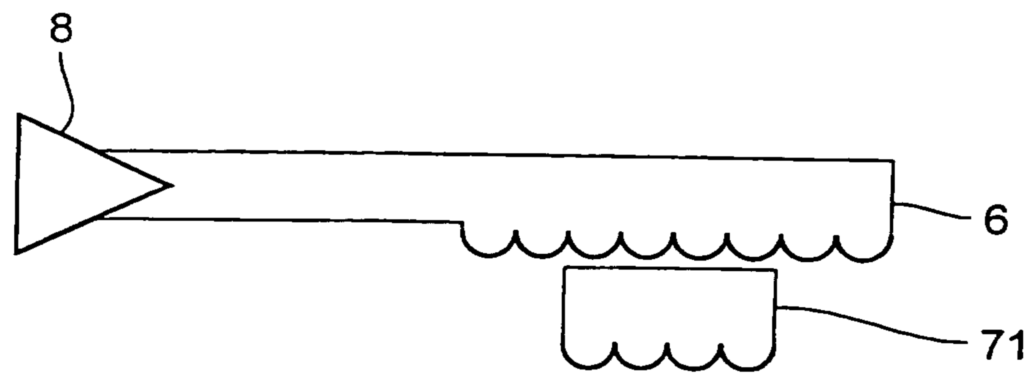


FIG. 4

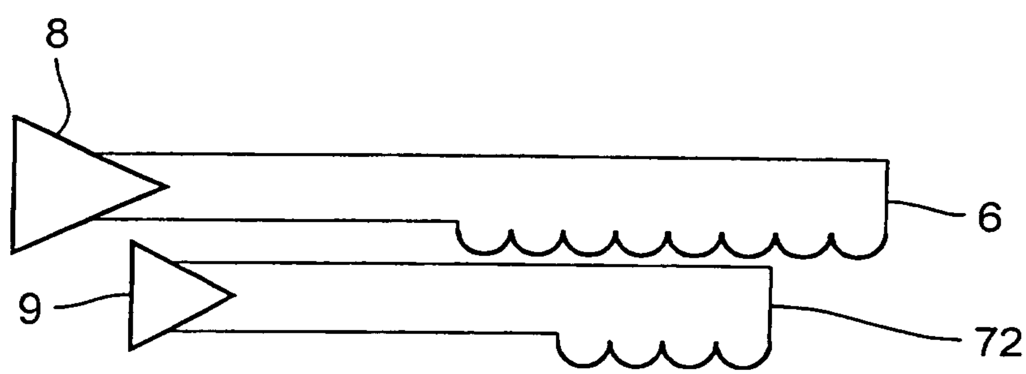


FIG. 5

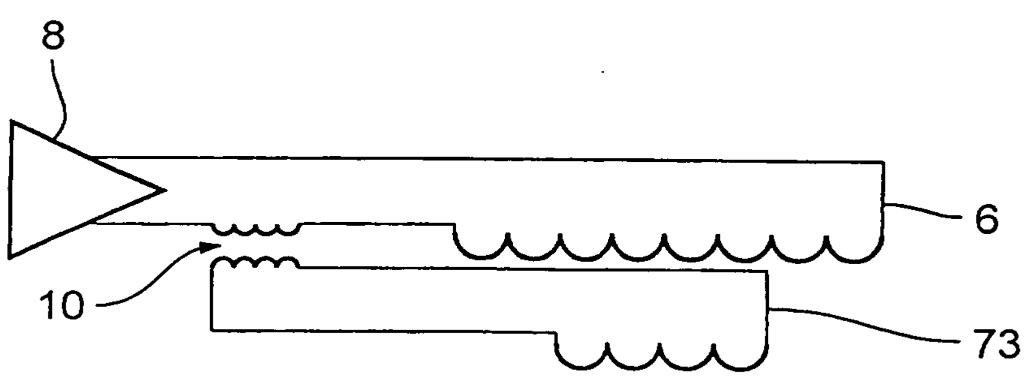
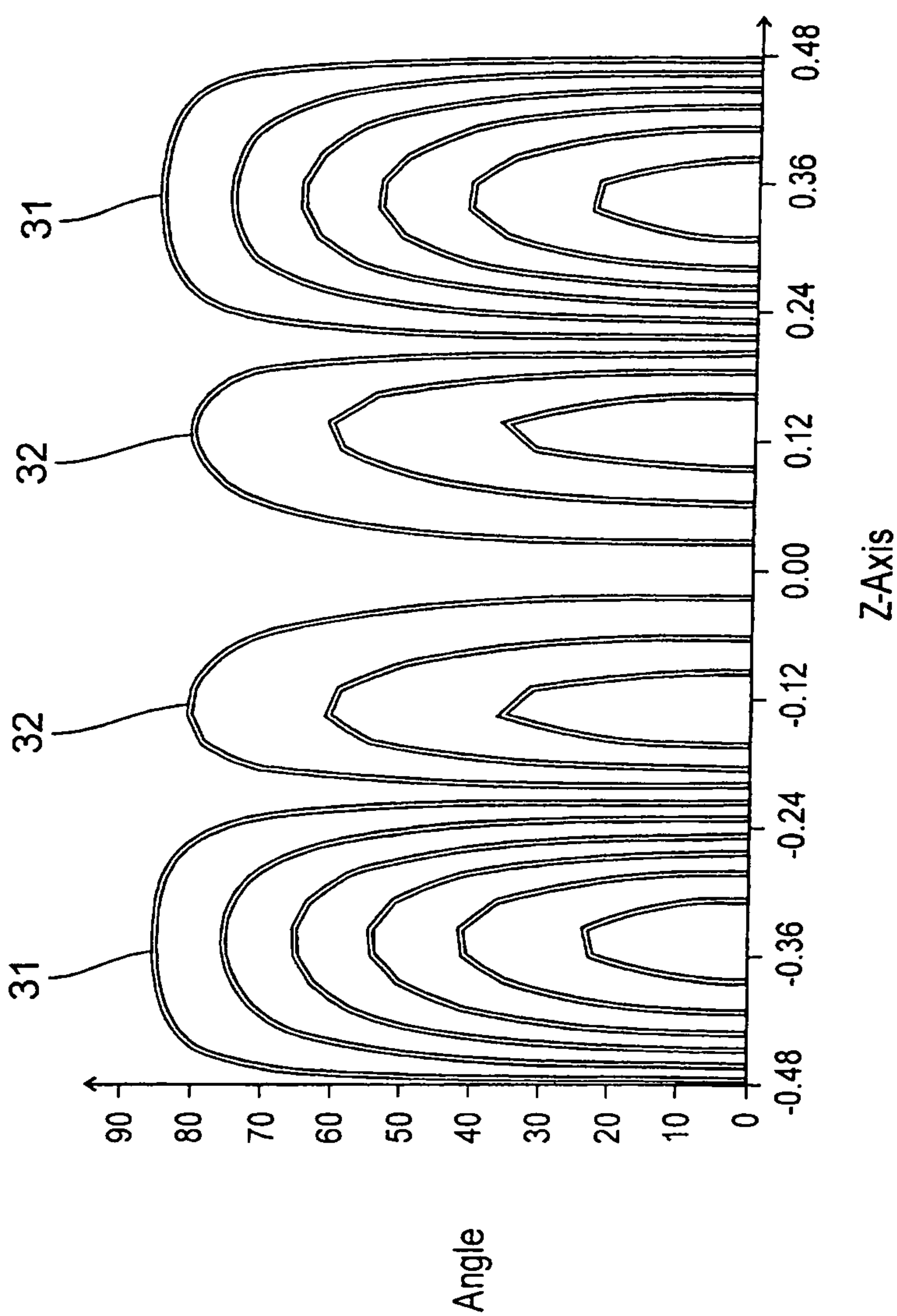


FIG. 6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32
32
31
Angle
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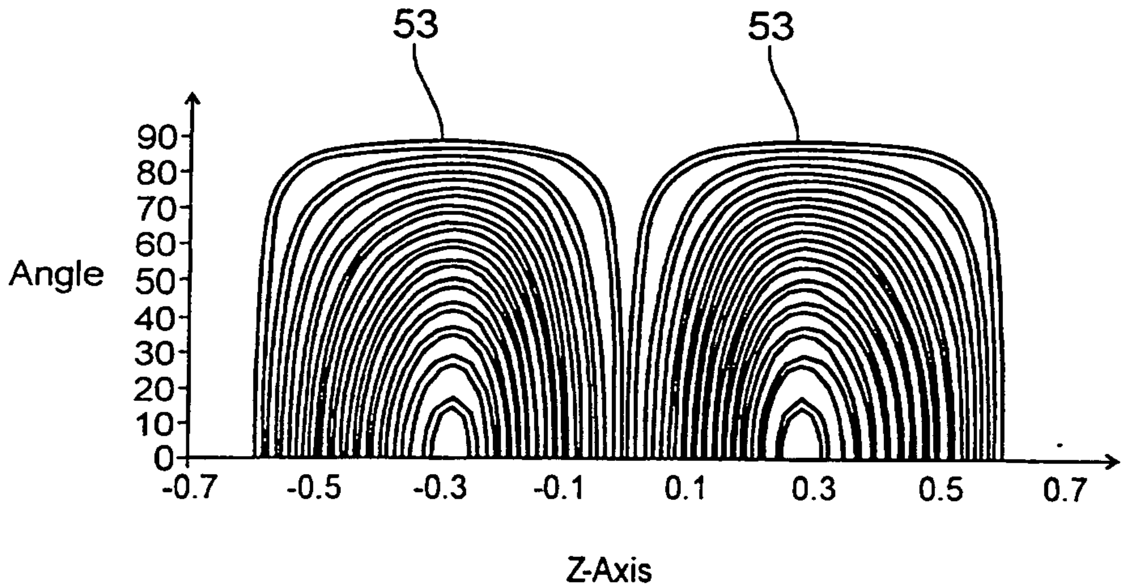
80
70
60
50
40
30
20
10
0
-0.48
-0.36
-0.24
-0.12
0.00
0.12
0.24
0.36
0.48
Z-Axis

FIG. 7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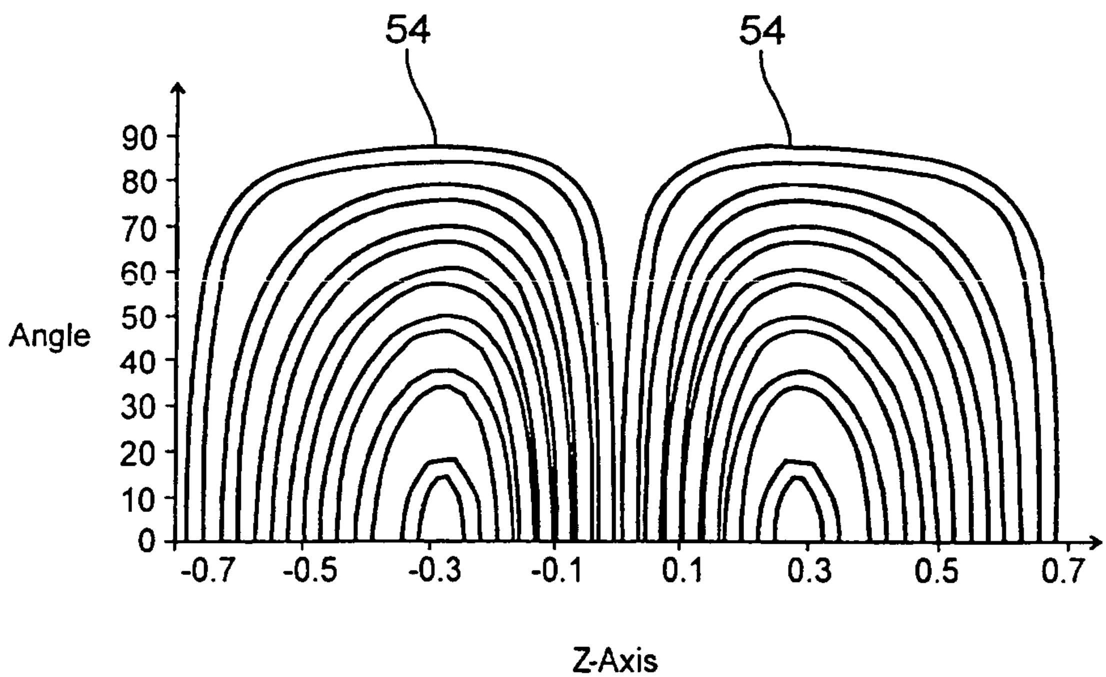
0.7
Z-Axis

FIG. 8a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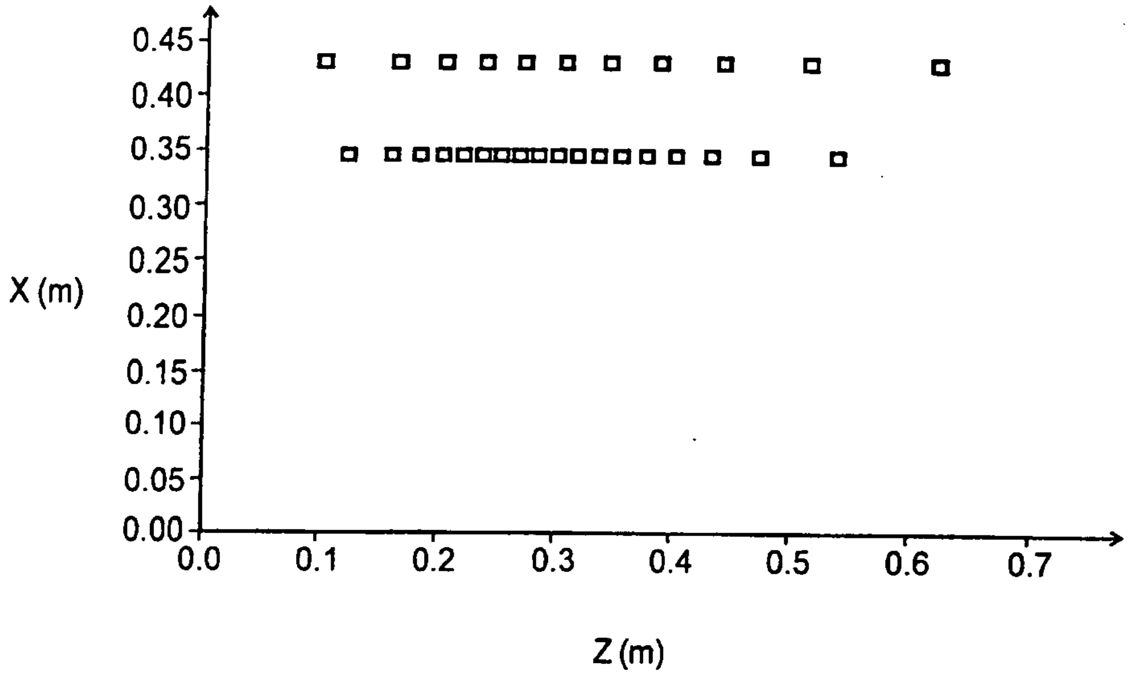
0.1
0.3
0.5
0.7
Z-Axis

FIG. 8b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0.15
0.10
0.05
0.00
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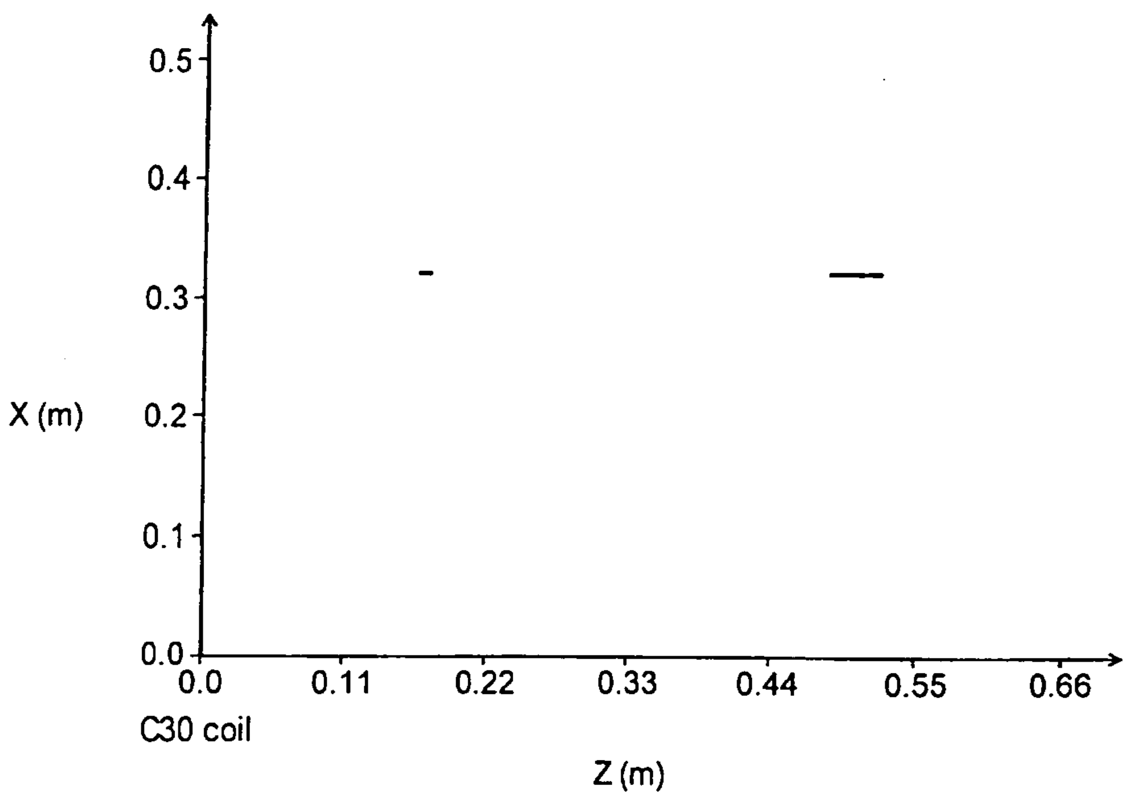
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Z (m)

FIG. 9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0.4
0.3
0.2
0.1
0.0
X (m)
0.0
0.11
0.22
0.33
0.44
0.55
0.66
C30 coil
Z (m)

FIG. 10

6/7

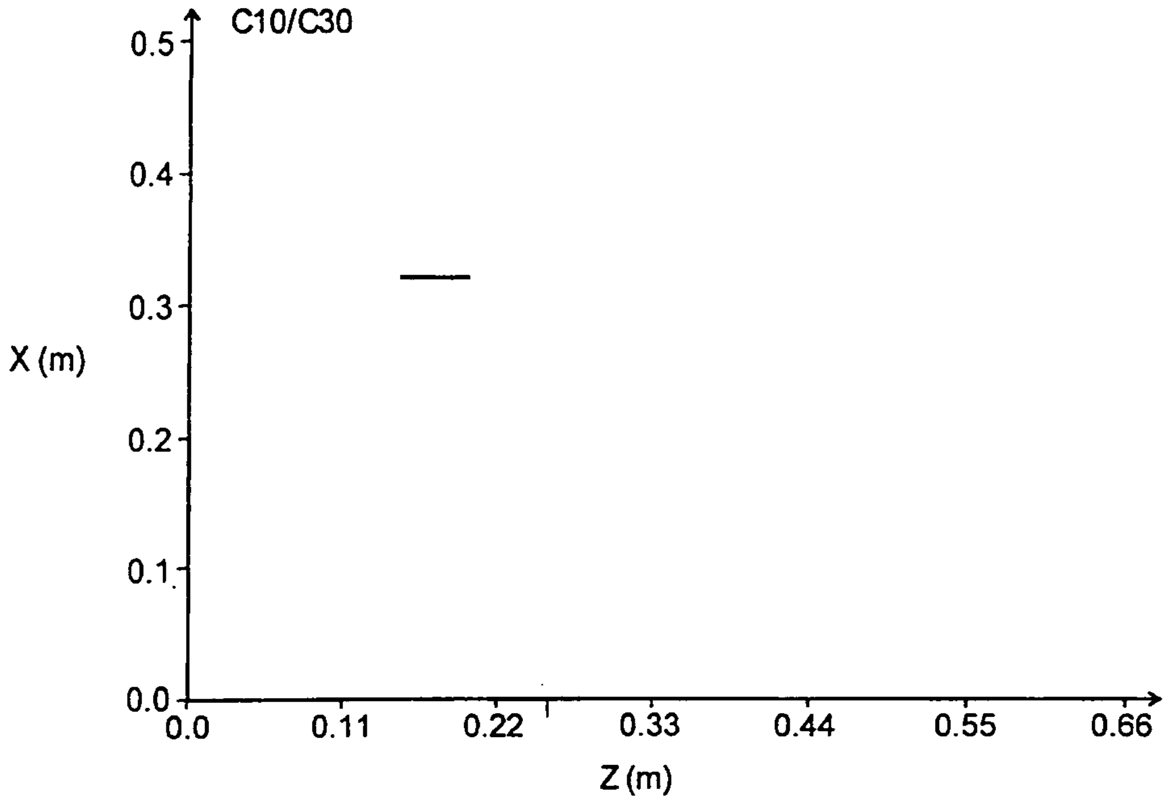

FIG. 11

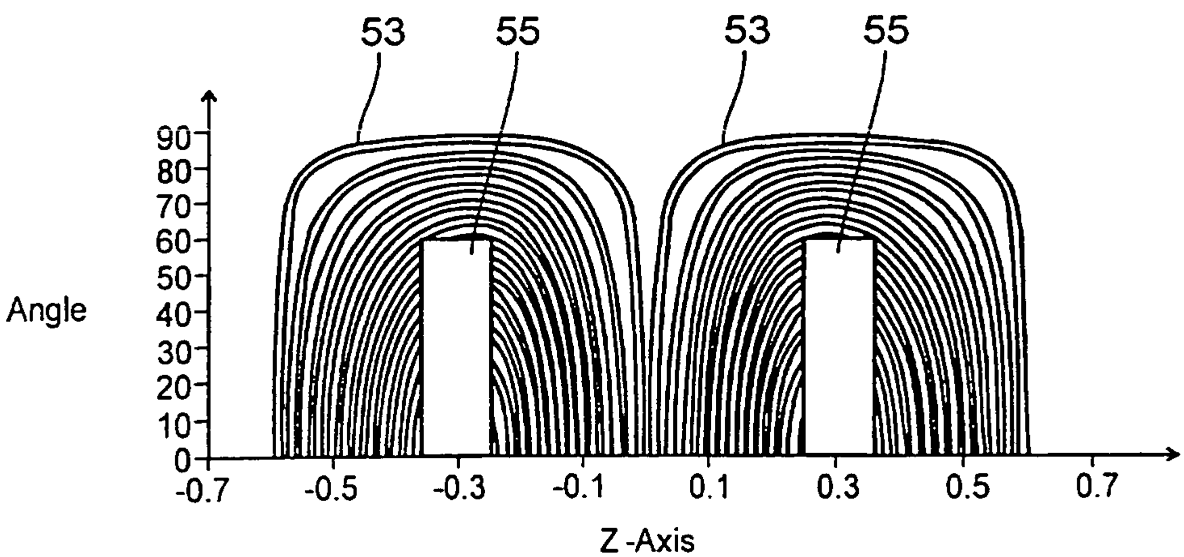

FIG. 12

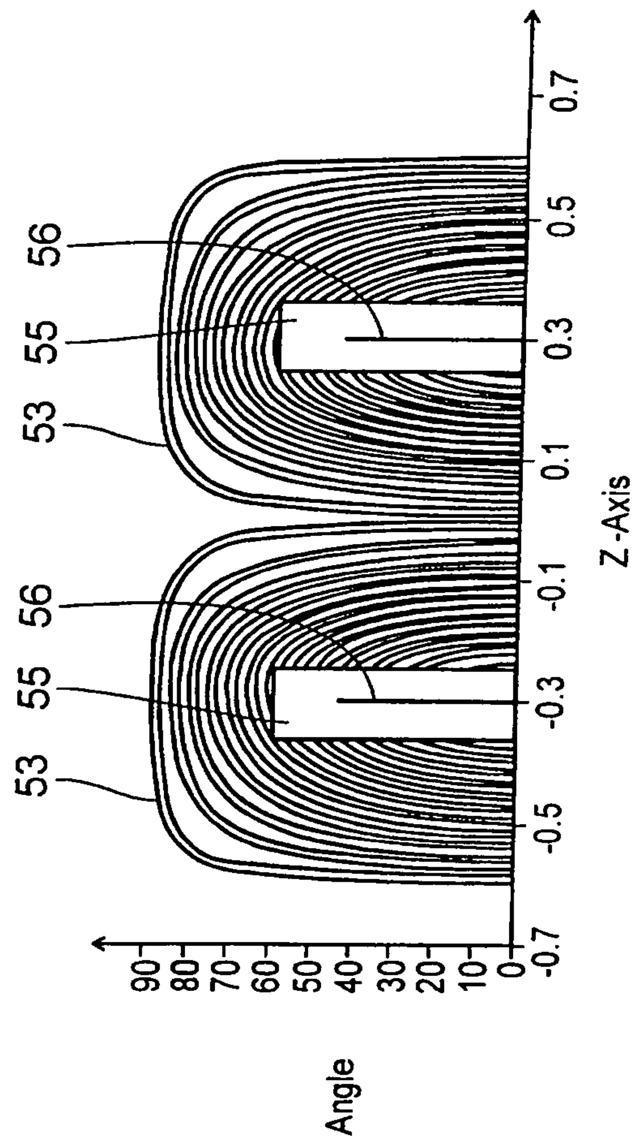

FIG. 13

22-12-2000